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COMPOSITE BOSS TECHNOLOGY

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Final Report

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13. ABSTRACT *(Maximum 200 Words)*

This program is closely related to the Liquid Hydrogen Composite Tank program contracted under F29601-95-C-0217. This project addresses the problem of excess weights of metallic components of composite tanks. Weight reduction and cost reduction are the primary goals of the program. Composite materials are used to replace the metallic fittings normally used for boss closures. IM7/977-2 was selected as the material system for the composite boss tank. The design of an 18 inch diameter by 30 inch long composite tank was revised to incorporate the attachment method into the dome structure of the tank. This also required changes to the mandrel tooling, which was provided by NASA Marshall Spaceflight Center (Huntsville, AL). Wall thickness of the cylindrical region of the tank is 0.084 inches. Composite boss closures were designed and filament wound as a pair on specially designed and fabricated tooling. After cutting apart, the boss closures were trimmed to size and installed on the tank with radial fasteners. Omni seals and Gortex® gasket materials were used to seal the boss closures in place. The tank is in inventory at the Air Force Research Laboratory at Kirtland AFB. Tests are planned with liquid hydrogen.

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Table of Contents

	Page
1. Introduction	1
2. Technical Discussion	1
A. Weight	2
B. Availability of super alloys	2
C. High Cost of super alloys	2
D. Difficulty of Machining	2
3. Methods, Results and Procedures	2
3.1 Material Selection	2
3.2 Design	3
3.2.1 Boss Details	3
3.2.2 Closures	3
3.2.3 Assembly	9
3.3 Fabrication	9
3.3.1 Tooling	9
3.3.2 Closure Fabrication	9
3.3.3 Closure Machining	12
3.3.4 18 Inch Tank/Integral Bosses	12
3.3.5 Location of Fastener Holes	16
3.3.6 Tank Machining	16
3.3.7 Boss Extension Sealing Surface	18
3.3.8 Assembly	18
4. Conclusions	19
4.1 Program Demonstration	19
4.2 Weight of Composite Assembly	19
4.3 Waste Incurred	19
4.4 Hand Lay-up	19
4.5 Payloads	19
5. Recommendations	19
5.1 LH_2 Drain and Fill Test	19
5.2 Evaluate best sealing technology	19
5.3 Fabricate a scaled up tank	19
5.4 Consider manufacturing process	19
5.5 Study	19
5.6 Change manufacturing procedure	19

List of Figures

		Page
Figure 1	Tank and Boss Configurations	4
Figure 2	Details of Boss Buildup	5
Figure 3	Schedule showing the filament winding and hand layup sequence	6
Figure 4	Configuration of the filament wound and machined closures	7
Figure 5	Layup sequence for the small closure bottle	8
Figure 6	Tank assembly	10
Figure 7	Set of two boss extension dams	11
Figure 8	Layup sequence	13
Figure 9	Photograph: Tank after application of the first boss build up sequence	14
Figure 10	Photograph: Final filament wound tank	15
Figure 11	Cure Cycle	17

Composite Boss Technology
Contract F29601-97-C-0086
Final Report

1. INTRODUCTION

The suggestion for this program and the innovation behind it resulted from the weight reduction and cost reduction goals of the expendable launch vehicle (ELV), the Improved High Payoff Rocket Propulsion Technology Program (IHPRPT) and the Military Space Plane. For all of these programs, major weight reduction is feasible based on elimination of the metallic liner in the liquid propellant tankage system. The initial research and development program for design, fabrication and test of 18 inch and 4 foot diameter linerless tanks was completely successful. The logical next step was to reduct the weight even further by changing the metal boss components to composite materials. Accomplishment of this goal was targeted by the award of the Composite Boss Technology contract to Wilson Composite Group, Inc. (WCGI).

Over 85% of the weight of a linerless cryogenic tank relates to the metallic bosses and closures. The primary approach taken in the composite boss program was to integrate the boss and boss attachment structure into the composite wall of the tank and use separate composite boss closures to seal the outlets of the tank. This approach formed the basis for this Phase I Small Business Innovative Research (SBIR) contract. This document is the final report under this program.

2. TECHNICAL DISCUSSION

During the past 4 years, a Broad Agency Announcement (BAA) program has been ongoing, performed by WCGI under contract from Air Force Research Laboratory, initially at Edwards AFB then following the Composite Development Laboratory move, at Kirtland AFB in Albuquerque, NM. The work statement for the program was to fabricate two 18 inch linerless composite tanks with metallic closures and subject one of them to a series of fill and drain tests at Marshall Space Flight Center using liquid hydrogen. The linerless composite tank concept was successfully proven during this testing. The objective of the final phase of the program was to design and fabricate a thin walled (.84 inch) linerless composite tank, 46 inches in diameter and approximately 74 inches long. Manufacturing of the tank was successful and resulted in the current program which is the next step in reducing the weight of propellant tankage and thus increasing the mission payload.

Experience from earlier fabrication efforts demonstrated that the next area of investigation and innovation is in reduction of weight of the bosses and closures which have previously been metallic and most generally super alloys. The demands of the deep cryogenic environment requires current tanks to use metallic bosses and closures of alloys such as Nitronic 60, Invar Titanium and Inconel 718. All of these materials are expensive and difficult to

machine. In this program the goal is to demonstrate the design and fabrication of an 18 inch diameter tank (32 inches long) using the existing 18 inch tank design with no liner and a wall thickness of .84 inches. There are four factors which this program attempts to mitigate: A) weight, B) availability of super alloys and C) high cost of the super alloys and D) difficulty of machining.

A. Weight

The completed demonstration design of a linerless cryogenic tank is 46 inches in diameter and has metallic bosses and closures which comprise 85 % of the total weight of the tank. As the size of the tank increases, the size of the tank openings becomes less as a percentage of tank diameter but the metallic bosses, attach rings and closures still represent significant unnecessary weight when compared to composite bosses. This unnecessary weight significantly reduces potential payload.

B. Availability of super alloys

During fabrication of the LH_2 program tanks, obtaining super alloy forged billets was difficult and time consuming. It was also determined that U.S. defense initiative program reductions have lead to a reduction in the availability of super alloy stock at metal distribution warehouses for both plate stock and forged billets.

C. High cost of super alloys

The limited availability of super alloys has brought about a significant increase in cost for the materials. World market shortage of chromium has also helped to increase prices. Mill run orders are possible but require large inventory for minimal use.

D. Difficulty of Machining

The available materials are inherently difficult to machine. This is especially true of Invar, Nitronic 60 and Inconel 718. A solution to these problems of weight and cost was to consider a composite alternate to the metals. A principal objective of the program was to design and manufacture a filament wound 18 inch diameter tank with integral composite bosses and filament wound composite closures.

3. METHODS, RESULTS AND PROCEDURES

3.1 Material Selection

Several composite material systems were initially considered as candidates for this program. Two of these are Toho G40-800 /977-2 and IM7/977-2. Three other materials were considered:1) a new material from the Air Force Research Laboratory, Wright Laboratory Materials Directorate, currently with no number or name and, 2) a new family of toughened

epoxy materials which are low temperature (14°F) non-autoclave cured materials LTM45 and LTM25 from the Advanced Composite Group in Tulsa, Oklahoma. A complete study of all the materials was beyond the scope of this contract. Three different forms of material went into fabrication of this 18 inch tank: 1) Tow preg, 2) Tape preg, and 5-harness satin weave fabric. All materials with the exception of the fabric were transfered from the 46 inch tank contract. The tow preg is Toho G40-850. Tape preg is Thornel T650-42 and the fabric is AS4. The resin selected is the Fiberite toughened epoxy 977-2 with both the G40-800 fiber and the T650-42 unidirectional tape. The AS4 Cloth was impregnated with a Fiberite toughened epoxy 977-3. No significant differences were noted in cure cycle requirements for the resins and properties of the G440-800 and T650-42 were close enough to IM7 not to impact this program. The AS4/977-3 was accepted for use on the program because it was not feasible or possible to obtain the small quantities of IM7 required with 977-2 resin impregnation.

3.2 Design

The design objectives were to modify the design of the thin walled (.84) 18 inch diameter tank to incorporate integral composite bosses and composite, filament wound closures. A design requirement was to define the boss configuration and to integrate the attach ring into the composite wall of the 18 inch diameter tank using a combination of hand layup and filament wound helicals and hoops to result in a structurally sound boss and tank assembly, capable of meeting the operating pressure requirement of 1200 psi and a burst pressure of 1800 psi at liquid hydrogen temperatures. The tank and boss configurations are shown in Figure 1. The design uses two staggered rows of ten .375 inch diameter holes in each boss extension to allow for joining the closures to the bosses.

3.2.1 Boss Details

Details of the boss buildup is shown in Figure 2. Schedule showing the filament winding and hand layup sequence is given in Figure 3. The hand laid materials on the domes of the tank were interspersed with the helical wraps, applied using the En-Tec filament winder. The boss extensions consisted of interspersed layers of unidirectional tape, five harness satin weave fabric and hoop wraps.

3.2.2 Closures

The closure design is simply a small filament wound tank formed by winding over a small steel mandrel. The design results in two closures from the one mandrel which must be machined at the ends and at the OD to provide sealing surfaces. The resulting part, prior to machining is approximately .5 inches in thickness. The configuration of the filament wound and machined closures is shown in Figure 4. The layup sequence for the small closure bottle is described in Figure 5 and consists of interspersed helicals and hoops with five harness satin weave fabric laid at +/- 45 degree angle with the longitudinal axis of the bottle and interspersed between the last three hoop layers.

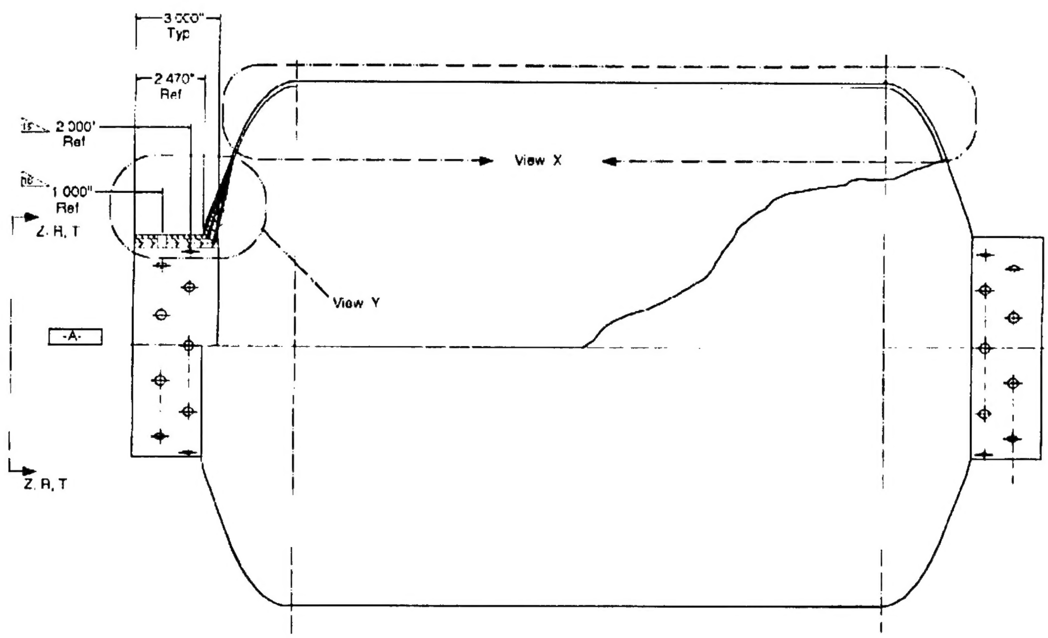


Figure 1. Tank and Boss Configurations

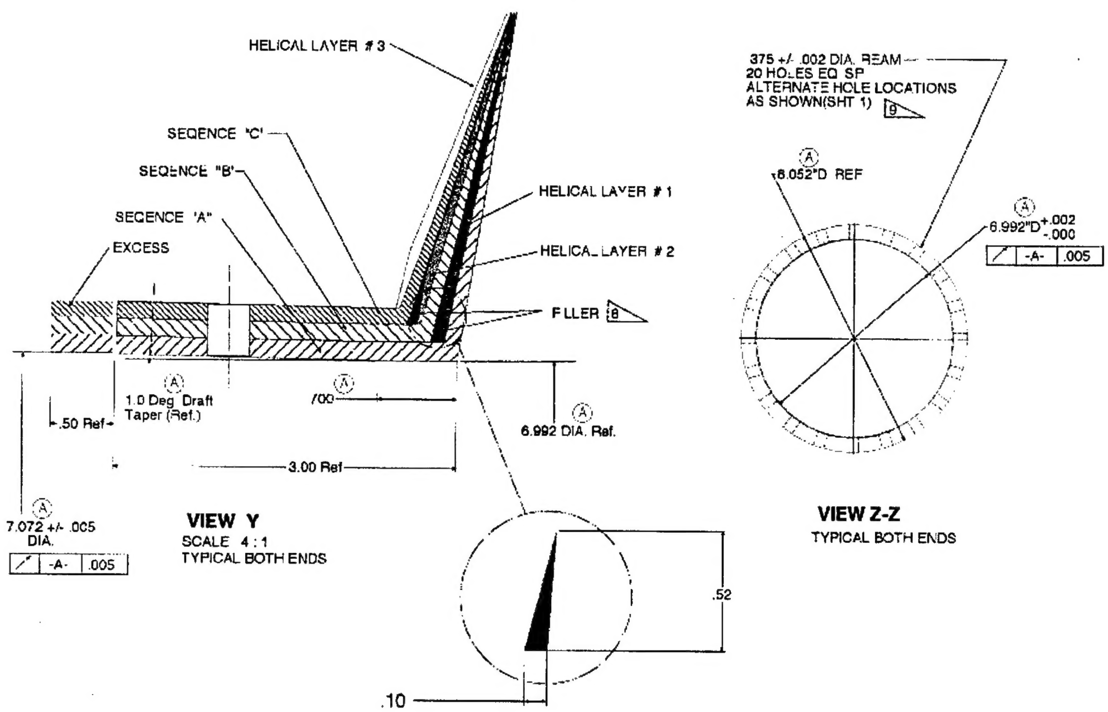


Figure 2. Details of boss build-up

Sequence No.	Layer No.	No. of Plies/Layer	Material Type	Angle	"A"(Inches)	"B"(Inches)	"C"= "A"+"B" +.5(Inches)	
A	A1	2	Tape	0	3.00	3.10	6.60	14
	A2	1	Cloth	45	3.00	2.40	5.90	15
	A3	2	Tape	0	3.00	1.70	5.20	
	A4	2	Roving	90	2.97		3.47	
	A5	2	Tape	0	2.95	1.00	4.45	
	A6	1	Cloth	45	2.95	0.30	3.75	
	A7	2	Tape	0	2.95	0.65	4.10	
	A8	2	Roving	90	2.93		3.43	
	A9	2	Tape	0	2.90	1.35	4.75	
	A10	1	Cloth	45	2.90	2.05	5.45	
	A11	2	Tape	0	2.90	2.75	6.15	
	A12	4	Roving	90	2.90		3.40	
B	B1	2	Tape	0	2.77	2.85	6.12	
	B2	1	Cloth	45	2.77	2.25	5.52	
	B3	2	Tape	0	2.77	1.65	4.92	
	B4	2	Roving	90	2.75		3.25	
	B5	2	Tape	0	2.72	1.05	4.27	
	B6	1	Cloth	45	2.72	0.45	3.67	
	B7	2	Tape	0	2.72	0.75	3.97	
	B8	2	Roving	90	2.70		3.20	
	B9	2	Tape	0	2.68	1.35	4.53	
	B10	1	Cloth	45	2.68	1.95	5.13	
	B11	2	Tape	0	2.68	2.55	5.73	
	B12	4	Roving	90	2.68		3.18	
C	C1	2	Tape	0	2.57	2.60	5.67	
	C2	1	Cloth	45	2.57	2.10	5.17	
	C3	2	Tape	0	2.57	1.60	4.67	
	C4	2	Roving	90	2.55		3.05	
	C5	2	Tape	0	2.54	1.10	4.14	
	C6	1	Cloth	45	2.54	0.60	3.64	
	C7	2	Tape	0	2.54	0.85	3.89	
	C8	2	Roving	90	2.52		3.02	
	C9	2	Tape	0	2.50	1.35	4.35	
	C10	1	Cloth	45	2.50	1.85	4.85	
	C11	2	Tape	0	2.50	2.35	5.35	
	C12	4	Roving	90	2.50		3.00	

Figure 3. Shedule showing the filament winding and hand lay-up sequence

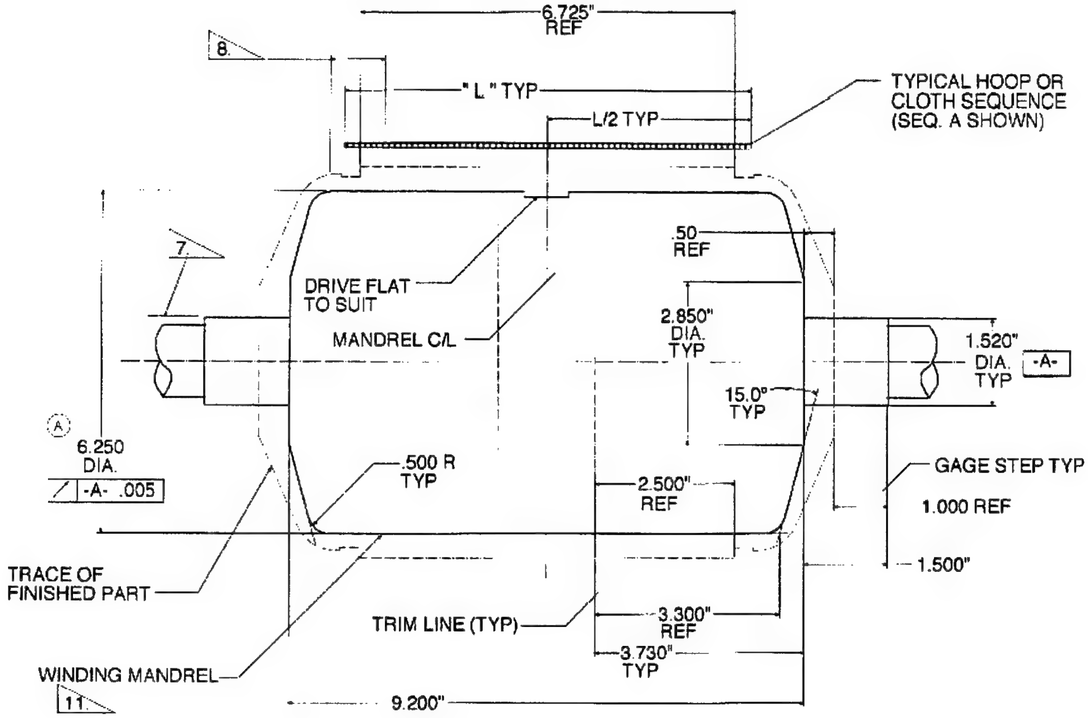


Figure 4. Configuration of filament wound and machined closures

WINDING TABLE- 2.

Sequence No.	Layer Type	No. of Plies	Material Type	Angle	"L"(Inches)	Seq Thk (Inches)	Cum Thk (Inches)
A	Hoop	2	Roving	90	7.2	0.015	0.015
B	Helical	8	Roving	+/- 19.5		0.059	0.074
C	Hoop	2	Roving	90	6.7	0.015	0.088
D	Helical	8	Roving	+/- 19.5		0.059	0.147
E	Hoop	4	Roving	90	6.2	0.029	0.177
F	Helical	8	Roving	+/- 19.5		0.059	0.235
G	Hoop	4	Roving	90	5.7	0.029	0.265
H	Helical	6	Roving	+/- 19.5		0.044	0.309
I	Hoop	3	Roving	90	7.8	0.022	0.331
J	Cloth	2	Cloth	+/- 45	7.6	0.028	0.359
K	Hoop	3	Roving	90	7.6	0.022	0.381
L	Cloth	2	Cloth	+/- 45	7.4	0.028	0.409
M	Hoop	10	Roving	90	7.0-7.4	0.074	0.483

10 3.

Figure 5. Layup sequence for the small closure bottle

3.2.3 Assembly

The tank assembly shown in Figure 6 consists of the 18 inch diameter tank with integral attach rings and bosses, and the boss closures with Omniseals installed in both ends of the tank using .375 inch diameter socket head shoulder screws, neoprene washers and hexagon 5/16-18 grade 8 nuts. A stainless steel drain and fill fitting is attached at the center hole of each closure and sealed using Goretex gasket material.

3.3 Fabrication

All filament winding and hand layup operations were performed at Air Force Research Laboratory, Kirtland AFB, Albuquerque, NM. Tooling was fabricated by the Thurm-a-Matic machine shop in Rancho Cordova, CA. Drain and fill fittings were fabricated at Excel Manufacturing in Albuquerque.

3.3.1 Tooling

Two pieces of tooling were designed and fabricated for this program: 1) a set of two boss extension dams (Figure 7), and 2) a winding mandrel for the closure bottle (see figure 4). All tooling was made from readily available mild steel and performed as planned during the fabrication operation. The 18 inch tank mandrel was a spare unit left over from the first phase of the LH_2 program. This mandrel required modification to prevent collapse during the autoclave cure process. Collapse had occurred when using the previous hollow 18 inch mandrels, resulting in serious wrinkles in the two tanks built for the original LH_2 program A modification plan was prepared and executed in which the mandrel was cut into two pieces perpendicular to its longitudinal axis and all but a three inch diameter core in the center of the mandrel was filled with a mixture of sodium silicate and sand. The mandrel was also lengthened slightly to properly fit the wind axis dimensions. It was believed that strengthening the structure in this manner would prevent collapse during cure and prevent wrinkles in the tank. The modification was a complete success and no wrinkles occurred.

3.3.2 Closure Fabrication

Closure tooling was shipped from Rancho Cordova, CA to Albuquerque, NM and was prepared for filament winding by carefully applying a layer of 548 skived teflon release tape to its entire surface. A filament winding team from WCGI prepared the mandrel and developed a filament winding program to meet the designed layup sequence. Winding over the small mandrel resulted in creating a bottle which would yield two closures. The closure unit was wound with no anomalies and was autoclave cured.

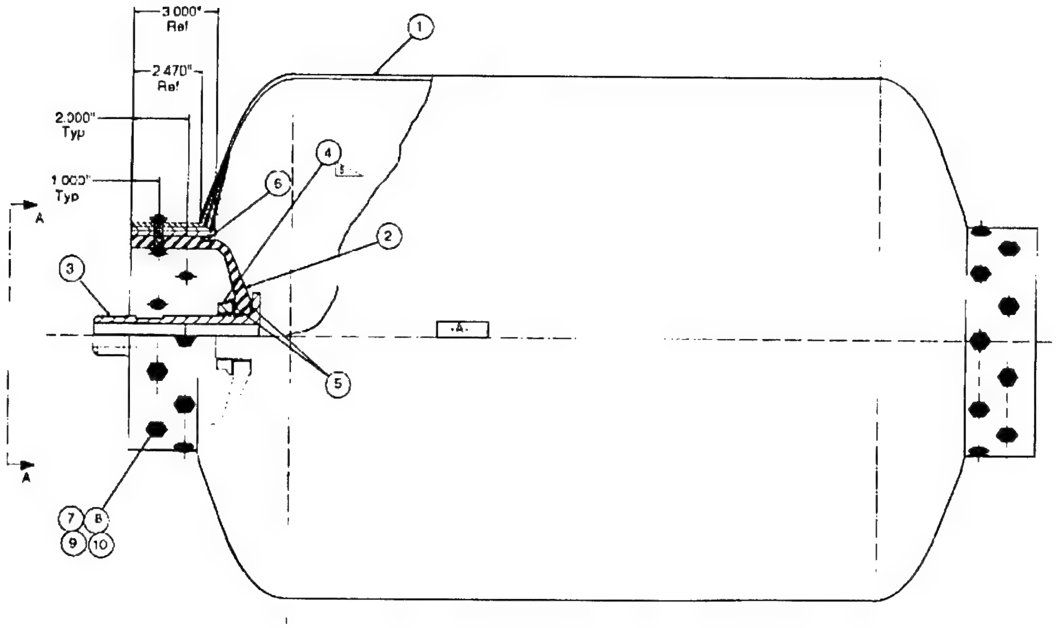


Figure 6. Tank assembly

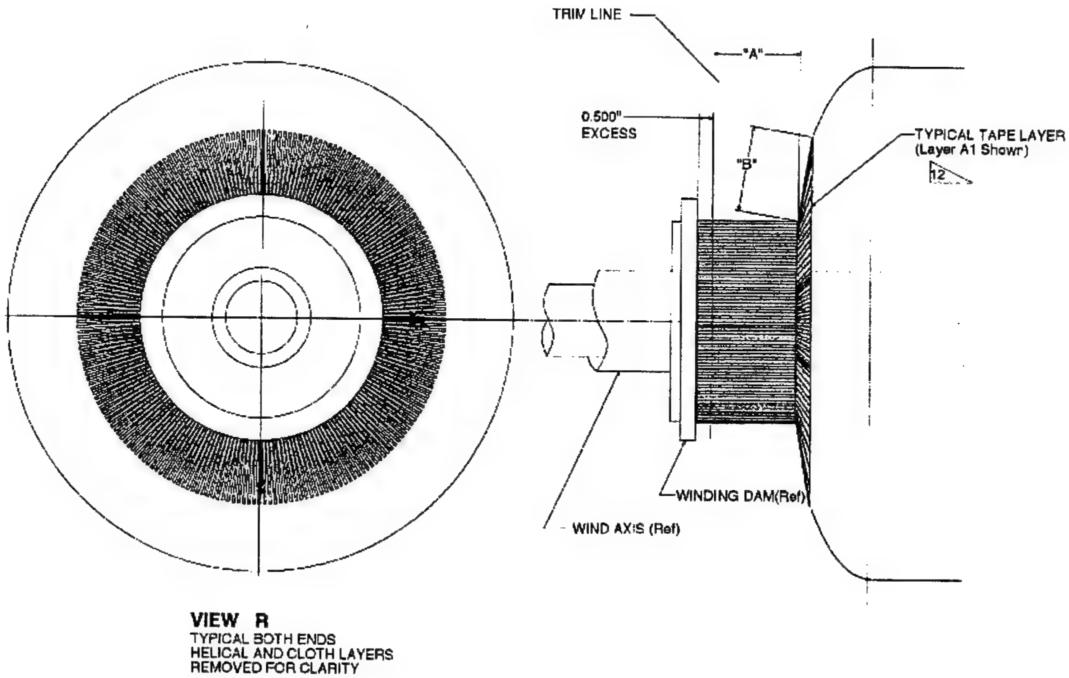


Figure 7. Set of two boss extension dams

3.3.3 Closure Machining

Machining of the closure unit was performed to yield the design configuration. The closures were machined on the Klausing lathe in the Phillips Laboratory machine shop. An electric motor with a belt driven tool holder was attached to the tool post. The tool was capable of controlled movement in the X and Y axis. The control worked well but the tool holder could only handle a 1/8" diameter shank on a carbide or diamond boss drill. This condition severely limited the speed with which a cut could be made without breaking the tool. The first closure required just over two diamond boss drills to complete.

A one degree taper was built into the boss extension internal diameter (ID) to facilitate removal of the drive dogs in the sand mandrel. This complicated machining of the closure because matching tapers had to be machined on the outside diameters of the closures to provide a good fit on assembly. In future tanks, the taper could be eliminated and replaced by a step increase in ID outboard of the seal surface. The face of the tank adjacent to the wind axis projection was machined to result in a .5 inch flat annular sealing surface. From this surface the location of the Omniseal groove on the OD of the tank was established and subsequently machined using a flat bottom carbide mill while rotating the part in a lathe. The cylindrical section of the boss closure was then machined to match the ID of the boss extension on the 18 inch tank with some reduction to allow for easy fitup. The distance from the Omniseal sealing surface to the end of the extension was measured and the same distance was marked and cut on the cylindrical section of the boss closure unit. After this operation was completed, the two closures were removed from the mandrel and prepped for fitup in the boss extension for drilling of fastener holes. Fabrication of the boss closure unit required approximately 16 manhours of effort. Machining of the parts required another 16 man hours. The composite closures weighed 1,738 gms.

3.3.4 18 Inch Tank/Integral Bosses

The 18 inch filament wound tank was laid up in compliance with the layup sequence (Figure 8) and is identical to the 18 inch tanks produced on the LH_2 contract with the exception of the integral composite attach ring and the boss extension cylinders. The sand mandrel was covered with 548 skived teflon tape to act as a release agent and the mandrel was loaded into the En-Tec filament winder. The winding program was developed and verified and winding commenced. The buildup of the integral bosses required a sigificant amount of hand layup work. The total thickness of buildup at the bosses was on the order of .6 inches. The boss material applied to the dome was interspersed with helical windings and the extensions of the bosses on the dams was interspersed with hoop wraps. After each hoop wrap of the boss extension, shrink tape was applied to the hoop winding and heated to provide compaction. The photograph (Figure 9) shows the tank after application of the first boss build up sequence and first helical pattern. Filament winding and hand layup of the tank and bosses took approximately twenty hours for a two person team for a total of 40 manhours. The final filament wound tank is shown in Figure 10. Vacuum bagging of the part was a labor intensive process.

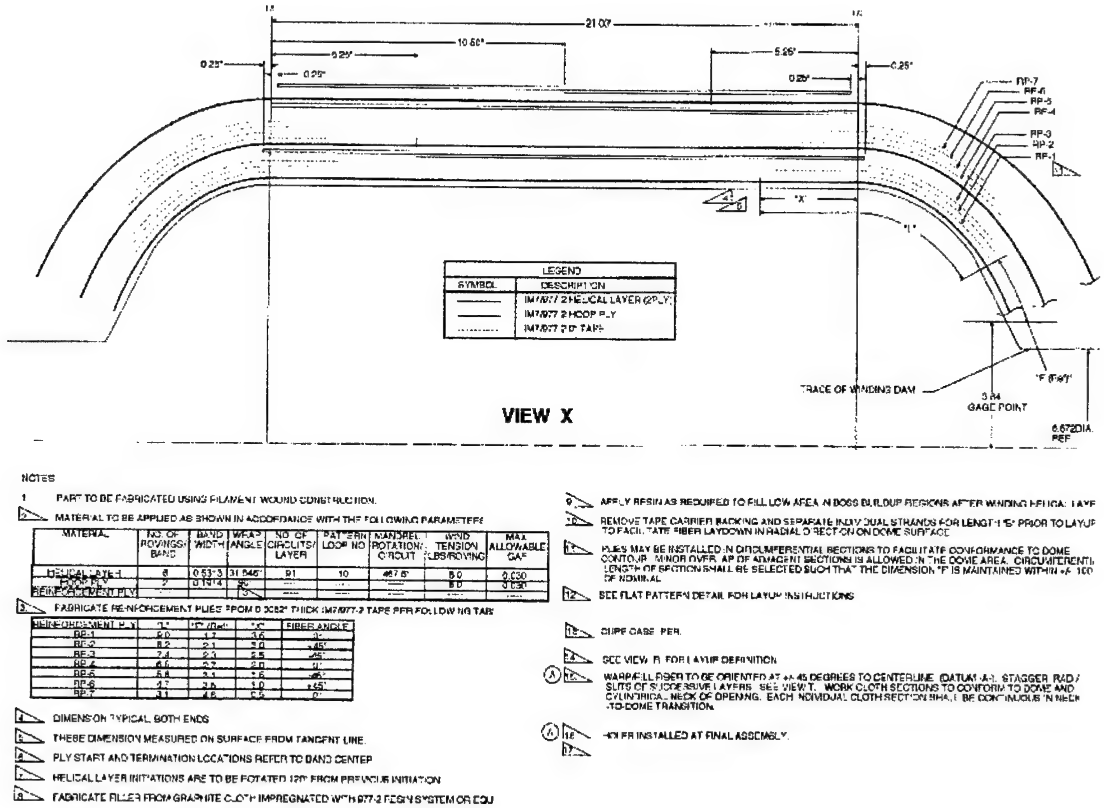


Figure 8. Layup sequence

Figure 9. Tank after application of the first boss buildup sequence

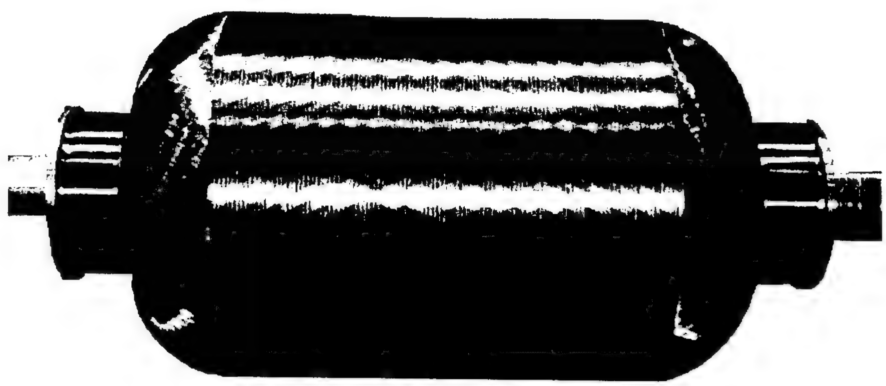


Figure 10. Final filament wound tank

The cure cycle used for the 18 inch diameter composite tank and the boss closure unit was identical to the cycle recommended and provided by Fiberite Inc. This cycle is shown in Figure 11. There were no problems and the cycle provided a good cure.

3.3.5 Location of Fastener Holes

The sand mandrel, as received from NASA Marshall Space Flight Center (MSFC), had an inconsistency in the depth to which the drive dogs were inserted into the sand mandrel. This condition caused one drive dog to have 0.700 inches on which to create the seal surfaces while the opposite end had only 0.600 inches showing. This condition caused the holes on the short end to be located 0.100 inches closer to the face of the tank dome. There is adequate surface to install the inboard row of fasteners without interference with the dome. The condition is only apparent upon close inspection and does not impact the function of the tank.

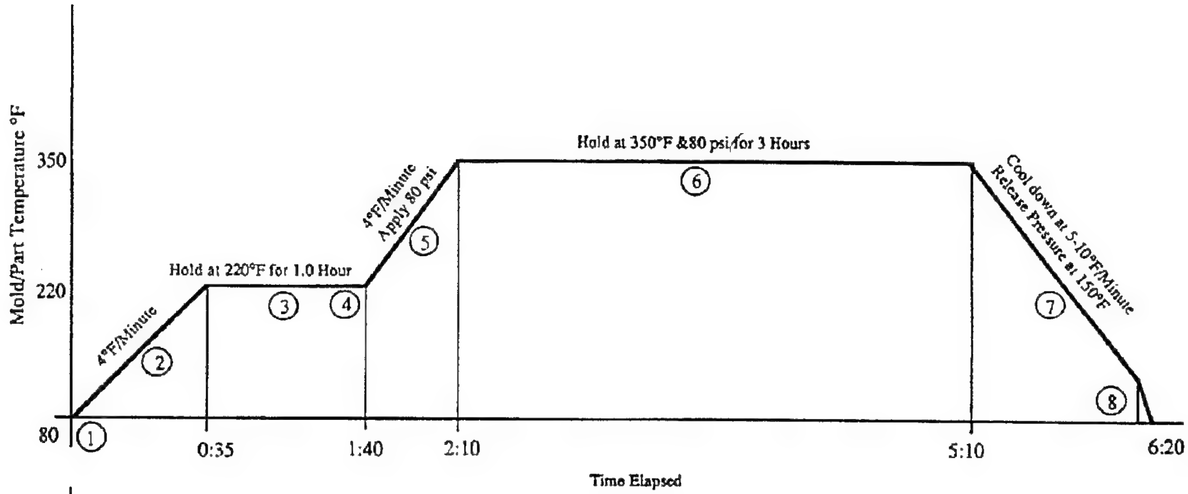
3.3.6 Tank Machining

Machining of the tank required 4 man-hours with most of the effort being expended on drilling of fastener holes through the boss extensions. Since no special tooling was available for this task, the machining was completed by using the En-Tec filament winding machine as a rotating and position tool. A drill motor was attached to the feed head of the machine and was used to power the diamond and carbide drills used to make the holes and clean up the "as wound" surfaces.

The "as cured" surfaces of the boss extensions had high and low areas which could cause uneven loading of the fasteners, therefore, a surface cut was made to produce a smooth cylindrical surface. Depth of cut was controlled to just allow the extension outside diameter to "clean-up". The resulting wall thickness of the extension is 0.405 inches at the outboard openings.

As previously described in paragraph 3.3.3, Closure Machining, one degree taper was built into the boss extension internal diameter (ID) to facilitate removal of the drive dogs in the sand mandrel. Matching tapers were machined on the outside diameters of the closures to provide a good fit on assembly.

After machining was completed, the mandrel and tank were removed from the En-Tec winder and the wind axis was removed. The mandrel and tank were placed in a fifty five gallon drum which was then filled to the top with hot tap water. The tank was allowed to soak overnight to dissolve the sand mandrel. The next day the mandrel was washed out with cold water and the metal drive dogs were removed through the boss openings. The empty tank was placed on a digital scale and weighed. It's weight was 6680 gms (14 lbs.-7oz).



APPLY 22-25 INCHES HG VACUUM. HOLD UNTIL PRESSURE IN AUTOCLAVE REACHES 20 PSIG MIN.

SETPOINT	O SEGMENT	1	2	3	4	5	6	7	8	
PV	O SETPOINT	80	220	220	220	350	350	150	70	
DEVIATION	O 1-4 ⎤ EVENT	--	--	--	80 psi	80 psi	80 psi	80 psi	--	
% OUTPUT	O 5-8 ⎦ EVENT	--	--	--	--	--	--	--	--	
DEV HI	O SEG TIME	00:00:30	00:35:00	01:00:00	00:05:00	00:32:05	03:00:00	00:50:00	00:20:00	
DEV LO	O RECYCLE	--	--	--	--	--	--	--	--	
PV HI	O NEXT SEG	2	3	4	5	6	7	8	8	
PV LO	O									
GAIN	O RECIPE ID									
RESET	O TIME INTO									
RATE	O START ⎤ TOD									
FILTER	O CLOCK ⎦ TOD									
BAND	O LOG OPTION									

Figure 11. Cure cyle

3.3.7 Boss Extension Sealing Surface

The sealing surface in the boss extensions (for the Omniseal) were created by using the visible "as-molded" surface of the drive dogs which were cast into the sand mandrel. Both sealing surfaces measured 7.004 inches in diameter, as molded. It should be noted that this surface could be better controlled and provide a superior sealing surface by building the surface up during fabrication (fiberglass may be a candidate for this) then grinding to produce the finished surface. To fill some imperfections in the sealing surface of the current unit, the seal area was coated with a light, brushed on layer, of room temperature curing epoxy. After the epoxy cured, it was lightly sanded using 400 grit sand paper, followed by crocus cloth. Some waviness of the surface still exists, which may prevent a good seal. Grinding would have been a better procedure for this.

3.3.8 Assembly

Assembly of the closures to the bosses required match drilling the fastener holes. The undrilled closures, with drain and fill fittings installed, were placed into the boss extensions, shimmed and held in the correct radial and axial positions while two holes were drilled through the closure using existing drilled holes in the extension as guides. Pins were inserted in the drilled holes to hold the two parts in position and the remaining holes were drilled. After the holes were completed the closures were removed from the tank and the Omniseals were installed in the seal grooves. Gaskets were cut from sheet Gortex material and placed between the flanges of the drain and fill fittings and the compression nuts were tightened to compress the Goretex band, creating a seal. The closures were then reinstalled into the boss extensions, aligned with the extension fastener holes and the 40 neoprene washers, shoulder bolts and nuts were installed, completing the assembly. The weight of the entire tank closure assembly with all metal hardware installed was 11,063 gms. Table 1 provides component weights for all items included in the overall tank assembly.

Table 1 - Component Weights

Component	Quantity	Total Weights
tank w/integral bosses	1	6680 gms
3/8 X 3/4 shoulder screws	40	960 gms
5/16 - 18 hex nuts	40	192 gms
3/4" neoprene coated washers	40	66 gms
5/8" neoprene coated washers	40	53 gms
Omniseals	2	36 gms
SS drain/fill fittings	2	2290 gms
Gortex gaskets	4	48 gms
Closures	2	1,738 gms
Total Weight		11,063 gms

4. CONCLUSIONS

4.1 The program demonstrated that design and fabrication of a filament wound tank with integral composite bosses is feasible and cost effective.

4.2 The weight of the composite assembly is significantly less than that of a tank with metallic bosses. Comparable weights of the metal boss and composite boss 18 inch diameter tanks are shown in Table II.

4.3 Compared to machining of metal bosses from super alloy forged billets, the amount of waste incurred in terms of material was insignificant. Approximately 2 lbs of waste resulted from the cutting of cloth and unidirectional tape reinforcements, whereas up to fifty percent of the weight of a forged billet may be lost to the machining process.

4.4 While hand layup of the integral bosses was time consuming compared to standard filament winding, it was less than the amount of time required to machine metallic fittings.

4.5 This program has demonstrated that the payload gains projected for all composite tanks are entirely feasible. Table III shows the estimated payload gains for various tank sizes of an LH_2/LOX system. Tank size ratios are based on standard liquid rocket engine propellant ratios.

5. RECOMMENDATIONS

5.1 Conduct LH_2 drain and fill tests on the tank to demonstrate integrity of integral bosses and closures.

5.2 Evaluate the best sealing technology for the all composite tank.

5.3 Fabricate a scaled up tank using the 46 inch diameter net metal mandrel for the SICBM second stage motor.

5.4 Consider manufacturing process changs to reduce the labor required for the boss extensions.

5.5 Study design of tank and tank tooling to reduce or eliminate boss extensions.

5.6 Change manufacturing procedure to eliminate matching, tapered surfaces on boss extension and closures. Use step design in extension segment.

Table II

Comparable Weights of 18 inch Pressure Vessels

Component	Metal Lined Composite Tank with Metal Bosses (lbs)	All Composite Tank (lbs)
Liner	17.0	0.0
Shell	9.0	14.7
Attach Rings	12.7	0.0
Closures	31.6	3.83
Seals	0.08	0.08
Washers	2.6	0.3
Fasteners	3.0	2.54
Gaskets	0.3	0.1
TOTAL	76.28	21.6

Table III

Estimated Payload Gains for Various Sizes of LH_2 and LOX Tanks

Tank Diameter (feet)	LH_2 Tank Weight Savings (lbs)	LOX* Tank Weight Savings (lbs)	Payload Gain (lbs)
1.5	55	13.8	69
4.0	290	72.5	362
10.0	2,566	642	3,208
12.0	4,400	1,100	5,500
20.0	16,502	4,125	20,627
35.0	62,565	15,641	78,206
LOX tank weight savings estimated at 25% of LH_2 tank weight savings			

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